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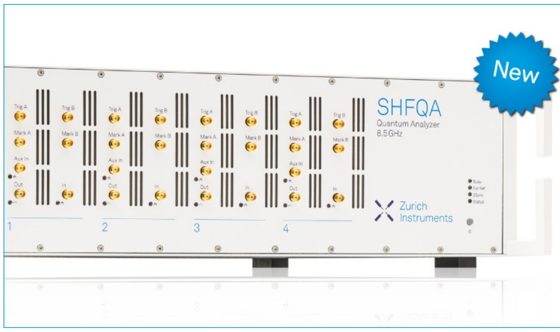

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An Intelligent System for Improving the Process of Hydromechanical Extrusion

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Abstract. An intelligent software system is developed for improving the process of hydromechanical extrusion enabling semi-fluid friction of the bar on the container walls and on the die mouth to be created, thus providing a favorable action of friction forces due to the fact that the velocity of the lubricant layer exceeds that of the bar. Herewith, extrusion pressure and the degree of strain inhomogeneity decrease significantly, and the bar–tool contact decreases, this being particularly relevant for metals adhering to the tool.

INTRODUCTION

The aim of the study is to design an intelligent software system for scientific research on plastic deformation of products made of difficult-to-form inhomogeneous metal materials and composites using improvement of the hydromechanical extrusion process as an example.

The application of hydromechanical extrusion (hereinafter referred to as HE) enables one to create semi-fluid friction of the bar on the container walls and on the die mouth [1]; this provides a favorable action of friction forces since the lubricant velocity exceeds that of the bar [2]. Herewith, extrusion pressure and the degree of strain inhomogeneity decrease significantly, and the bar–tool contact decreases; this is particularly relevant for metals adhering to the tool [1, 3].

As was reported in [2, 3], various CAD and CAE systems are used for the implementation of hydromechanical extrusion. Basic tool dimensions are container length and diameter, the taper angle and the length of the parallel land of the die, which were thoroughly discussed in [1–3].

The application of the experimental-analytical method enables us to form a Knowledge Base containing the law of motion of material particles, constitutive equations, and plasticity diagrams for structurally inhomogeneous material constituents, which are found experimentally, with few variable parameters being included in the equations. The variational problem is solved with the application of the extreme theorems of perfect plasticity, with the effect of technological factors taken into account; as a result, the strain state of the material is specified. The stress state in macro- and microvolumes is determined in accordance with the layered approach. When determining the strain state, we experimentally determine the equations of streamlines and the strains of material fibers. With the application of the phenomenological theory of fracture, the damage of structurally inhomogeneous material constituents is predicted. The method is developed for materials regularly structured in the initial state.

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METHODOLOGY

The intelligent system (hereinafter referred to as IS) for improving the HE process is designed with the consideration that processed and integrated experimental data, as well as mathematical models of the process constructed based on these data, must be obtained at the output of the system. The adequacy and accuracy of the models is ensured by the whole complex of methodical, program, and other tools of the system.

The aim of designing the system is to use it for the construction and refinement of HE mathematical models, which can be applied to design, prediction, and control, and thus to enhance the effectiveness and quality of scientific research.

This aim is achieved by the systematization and improvement of the HE process on the basis of mathematical methods and computer facilities, by effective mathematical methods of experiment organization and planning, by techniques of processing and presenting research and test results as mathematical models having a specified form, and by applying mathematical modeling instead of full-scale testing and prototyping.

The main function of the system is obtaining research results by automated processing of experimental data and other information, constructing and studying HE models by the application of mathematical methods, intelligent procedures, experiment design and control.

RESULTS AND DISCUSSION

Let a simplified structure of the IS for improving the HE process be considered (see Fig. 1). The basic structural units of the system are subsystems that are parts of the system distinguished by some features. These parts are responsible for the implementation of certain automated research procedures and for obtaining relevant output documents.

Object-oriented and service subsystems, as well as a separate Database and Knowledge Base control subsystem, should be noted as parts of the IS.

The object-oriented subsystems allow one to obtain and process experimental data from specialized test stands during HE. For example, the working medium for HE (acting as a process lubricant) must possess special physical and mechanical properties providing a complete separation of the bar and tool surfaces under operating pressures. This medium must have good adhesion and high plasticity ensuring a continuous coating at a strain of up to 80-90%. At the same time, shear strength and viscosity under operating conditions are essential parameters of the working medium. The dependences analytically represented by a general mathematical model are the hypotheses forming a basis for the Knowledge Base.

For example, one of the hypotheses may contain a statement that the rheological model of the work material is described by the following dependence [4]:

$$\frac{\sigma_i}{\sigma_s}=\left(1-\exp\left(-\frac{\gamma}{\sigma_s}\xi_i\right)\right)\exp(-k\cdot\theta), \tag{1}$$

where σ_i is stress intensity, σ_s is yield stress, ξ_i is strain rate intensity, γ is the dynamic viscosity of the material, k is the temperature coefficient, θ is temperature, $\sigma_s/\gamma\xi_i$ is a dimensionless group characterizing the ratio of plastic to viscous material properties. When $\sigma_s/\gamma\xi_i \ll 1$, plastic properties prevail since $\sigma_i \approx \sigma_s$. In all other cases, the material is nonlinearly viscous.

This model is found in the Knowledge Base of the IS. The coefficients of the working medium model are determined by the Working Medium Study object-oriented subsystem on the basis of the Working Medium Study Results saved by the Database and Knowledge Base Control Subsystem in the corresponding Experimental Data Base.

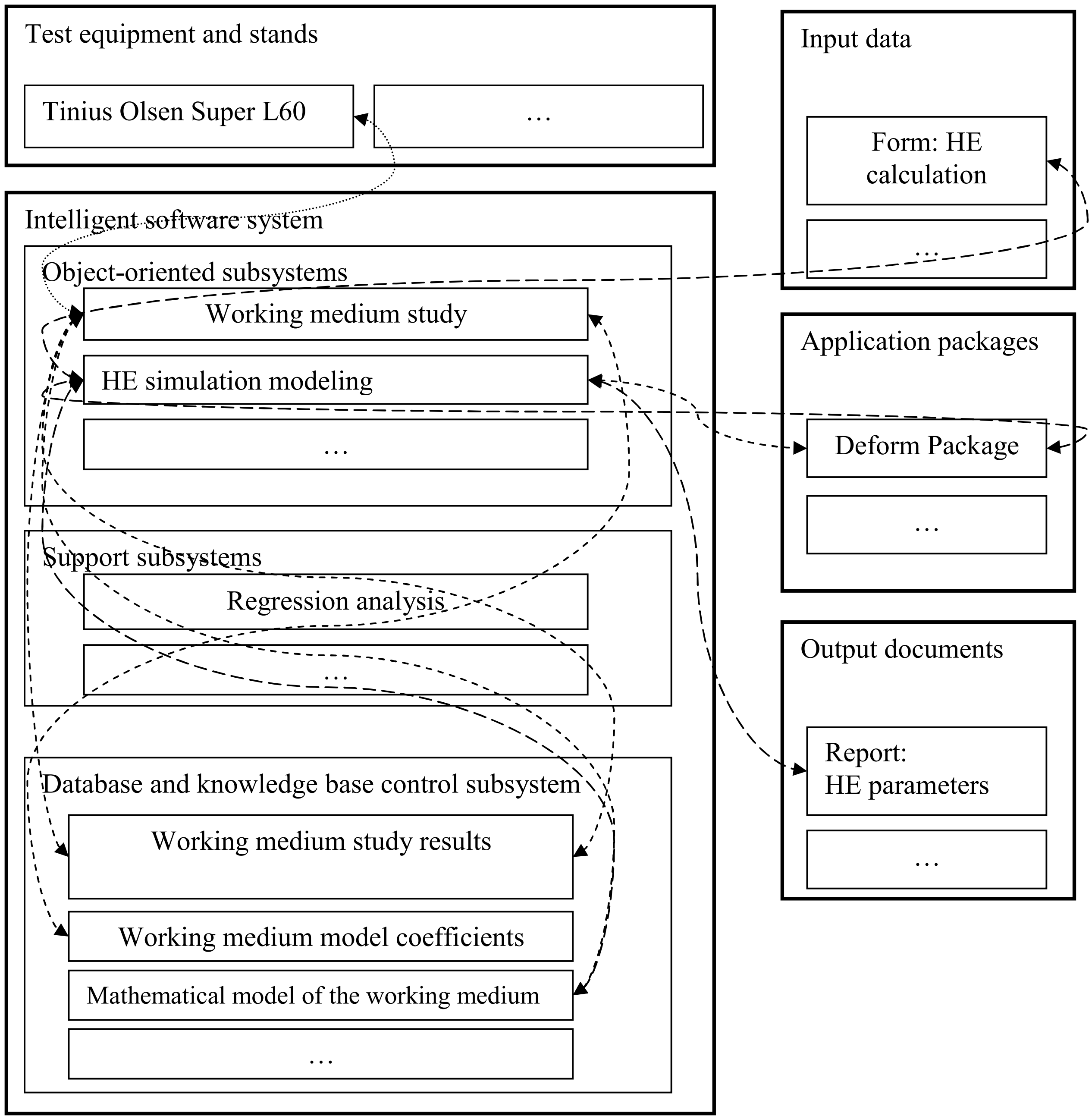

FIGURE 1. A simplified model of the structure of the intelligent software system for improving the HE process

Let us consider in more detail the Working Medium Study subsystem, where a dependence relating strain resistance to various technological parameters of the HE process is to be obtained. The most common method for constructing these dependences is tensile testing. However, such a test circuit is unacceptable for plastic paraffin used as the working medium. In this connection, the Working Medium Study subsystem designed with the use of Expert Systems technologies suggests that compressive testing be performed in order to study plastic paraffin. It also selects test equipment and reports the dimensions of the specimen, which in this case has the form of cylinder with a diameter of 45 mm and a height of 30 mm. Another output document is experiment design.

The specimens were upset in a Tinius Olsen Super L60 testing machine. Table 1 shows some results of testing plastic paraffin for compression. The results are saved in the Experimental Data Base.

TABLE 1. Results of the experiment on cylindrical specimen upsetting

Displacement H_{curr}, mm	Strain $\varepsilon=\ln H_0/H_{curr}$	Force P, N	Yield stress σ_s, MPa	Strain rate $\dot{\varepsilon}$, s^{-1}	Temperature θ, °C
2	0.07	128	0.076	0.0035	18
6	0.23	793	0.394	0.0038	22
10	0.41	906	0.364	0.0041	26
14	0.65	1080	0.332	0.0046	30
18	0.94	1410	0.299	0.0052	34
22	1.37	2380	0.280	0.0062	38
26	1.89	5640	0.292	0.0076	40

The experiment design can be corrected automatically during the experiment. After the experimental data have been obtained, they enter the service subsystem, where Regression Analysis is carried out, and the Working Medium Model Coefficients are calculated for the hypothesis on the Mathematical Model of the Working Medium proposed in [5]. If the model is recognized to be adequate [6], the following equation is obtained:

$$\frac{\sigma_i}{\sigma_s} = \left(1-\exp\left(-11{,}17\xi_i\right)\right)\exp\left(-0.021\cdot\theta\right). \tag{2}$$

After the Experimental Study Results have been processed, we determine the strain rate dependence of the yield stress of plastic paraffin, which is necessary for identifying the material model and which is subsequently used in the Simulation Modeling of the HE process.

The Application Packages allow us to use special tools for HE process modeling. For example, the Deform Package can be applied not only to analyzing the parameters of the HE process by the finite element method, but also to calculating tool strength, to determining strain inhomogeneity, and, on the whole, to improving the product quality.

CONCLUSION

Due to the use of the intelligent procedures constituting the system, HE mathematical models can be obtained and studied by the user’s conversational interaction with the system, data processing and mathematical model identification or construction being executed without human intervention.

The system involves the procedures of experiment design and control, which enable the use of modeling to correct experimental conditions and allow experimental information to be used for selecting a mathematical model from a given collection of similar models.

The system functioning results in hypotheses confirmation (or rejection), or in a collection of complete mathematical models satisfying specified requirements, as well as in processed research, observation, and measurement data.

The system operation results in output documents created according to the specified form and containing research results.

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